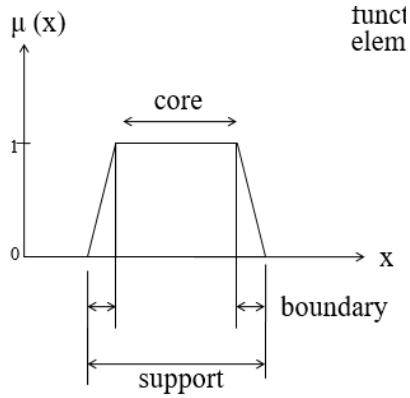
1- **Explain with example the meaning of following terms:**
Support – core – single ton – linguistic variables – linguistic values

- Support of a fuzzy set A is the set of all points x Є X at which $\mu_A(x) > 0$

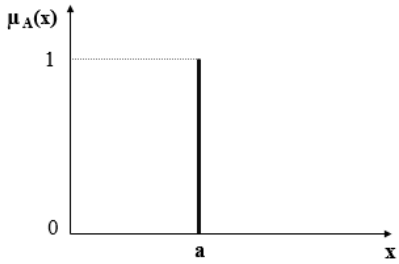
  Support (A) ={X | $\mu_A(x) > 0$ and x Є X}

- Core of a fuzzy set A is the crisp subset of X consisting of all elements with membership grade 1

  Core (A) ={X | $\mu_A(x) = 1$ and x Є X}

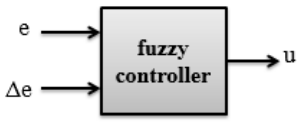


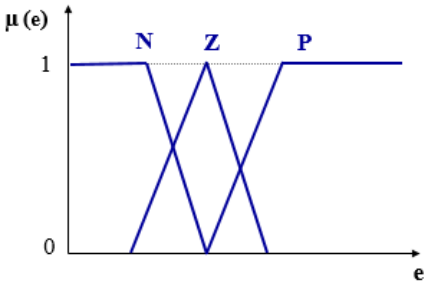
- Single ton: a fuzzy set is called single ton fuzzy set when the number of elements =1 with $\mu = 1$



- Linguistic variables: The labels of the fuzzy controllers inputs and outputs are called **linguistic variables** (Like error, speed, temperature, level, height, x1, A… etc.).
- Linguistic values: The labels of the fuzzy sets for inputs and outputs of the fuzzy controllers are called **linguistic values** (Like Negative, Zero, Positive, Slow, Medium, Fast, N, P, Z… etc.).

EX:

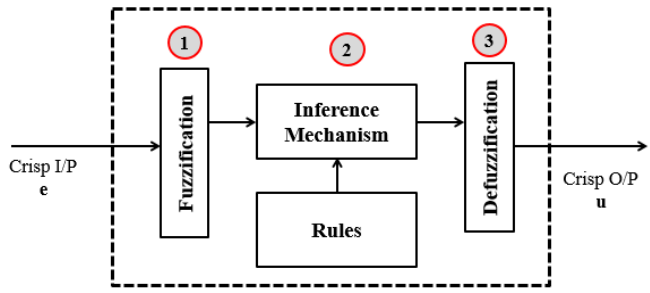




- e, Δe and u are linguistic variable.
- N, Z and P are linguistic values.

2- Explain the structure of fuzzy controller.

Fuzzy Controller Structure

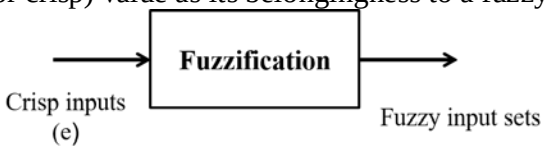


Fuzzy Controller

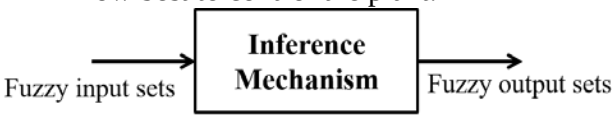
➢ Crisp means numeric (or real) value

The fuzzy controller contains three stages:

1. **Fuzzification**
   - The process that allows converting crisp (or numeric) values of the fuzzy controller inputs into a fuzzy input sets.
   - The fuzzification process actually provides a membership grade (μ) of a real (or crisp) value as its belongingness to a fuzzy set.



2. **Inference Mechanism**
   - **Rules**: is a set of IF-THEN statements including the expert's linguistic description that governs the performance of the controller.
   - **Inference mechanism**: that is the heart of a fuzzy controller; which emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.

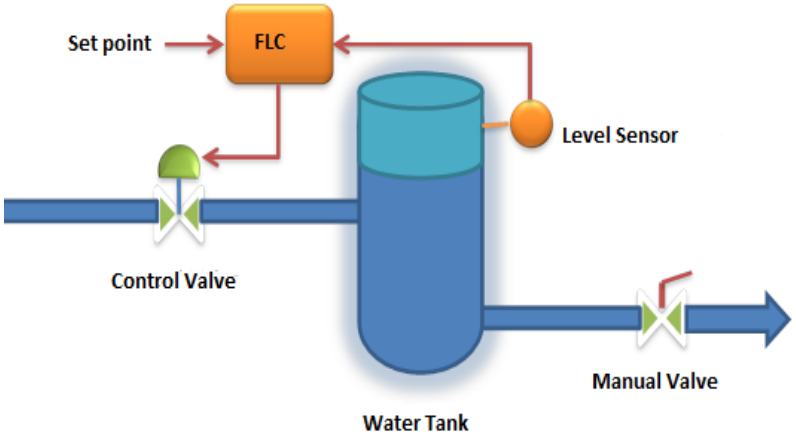


3. **Defuzzification**
   - Defuzzification is the inverse process of fuzzification in which a fuzzy quantity is converted into a crisp value.

3- Explain how the rules of fuzzy controllers include fuzzy logic concept.

AND / OR operators are used to join multiple conditions (in the IF part) and also are used to join multiple actions, these operators **include fuzzy logic concept.**

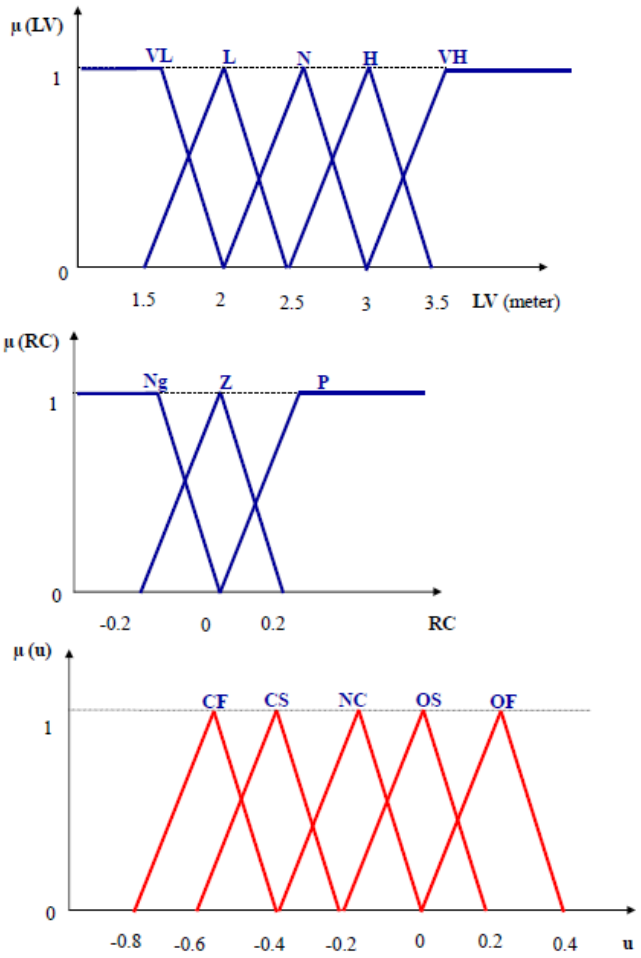
4- Consider the following hydraulic system:



Write suitable rules to design fuzzy controller to control the level of a liquid in the tank.

- The inputs to the fuzzy controller are the liquid level in the tank (LV) and the rate of change in level (RC). The output of the fuzzy controller (u) controls the valve position.

- Consider the inputs of the controller have five fuzzy sets: {VL, L, N, H, VH} for the input LV and three fuzzy sets: {Ng, Z, P} for the input RC. The output of the fuzzy controller u has five fuzzy sets: {CF, CS, NC, OS, OF}. These fuzzy sets are shown in the following figures.

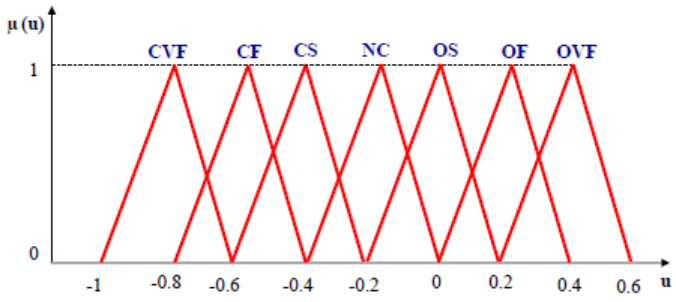


The labels of the fuzzy sets VL and VH stand for very low and very high.
(VL = "very_low", VH = "very_high")

The table of rules

LV\RC	Ng	Z	P
VL	OF	OF	OF
L	OF	OF	OS
N	OS	NC	CS
H	CS	CF	CF
VH	CF	CF	CF

5- Repeat Q (4) if we change the no. of fuzzy sets for the output of the fuzzy controller u to seven fuzzy sets: {CVF, CF, CS, NC, OS, OF, OVF}. These fuzzy sets are shown in the following figure.

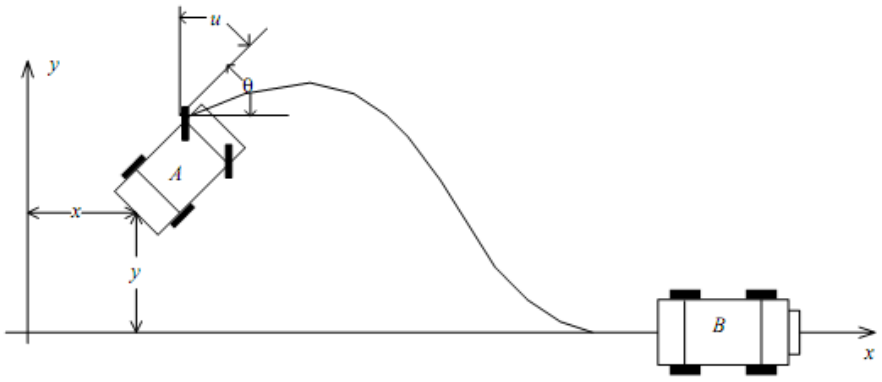


The labels of the fuzzy sets CVF and OVF stand for close very fast and open very fast.
(CVF = "Close_very_fast", OVF = "Open_Very_fast")

The table of rules

LV\RC	Ng	Z	P
VL	OVF	OVF	OF
L	OF	OF	OF
N	OS	NC	CS
H	CS	CF	CF
VH	CF	CVF	CVF

6- Consider a truck-parking control problem, as shown in the following figure:



A truck-driving control example

Write suitable rules to park the truck anywhere on the x-axis.

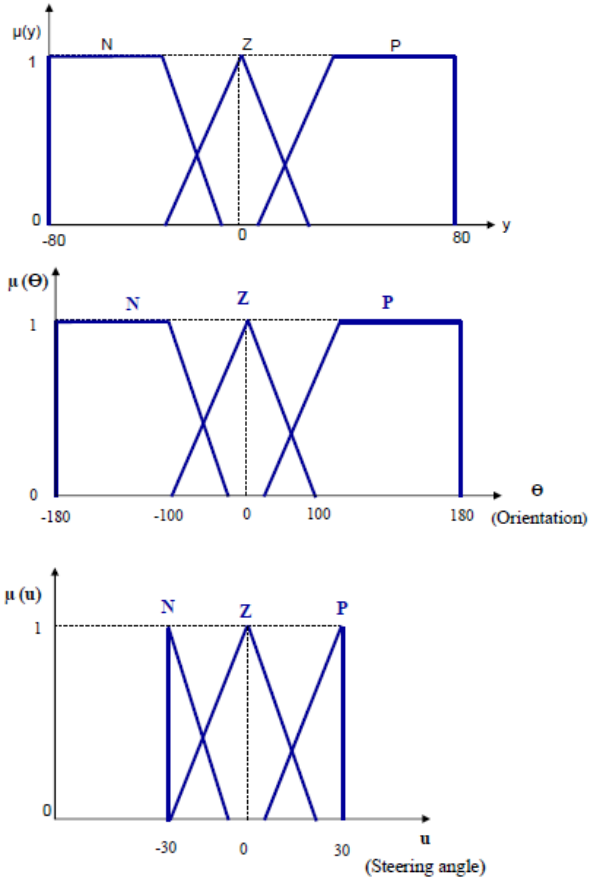
- Suppose that: the truck can move forward at a constant speed and the truck is equipped with sensors that can measure location **(x, y)** and orientation **(angle) θ** at all times.

- The fuzzy logic controller provides the control action u that rotates the steering wheels to guide the truck.

- The **inputs of the fuzzy controller** are the truck angle (**θ**) and the vertical position coordinate (**y**) while the **output of the fuzzy controller** is the steering angle (signal), **u**.

- Consider the inputs of the controller have three fuzzy sets: {N, Z, P} for the input **y** and {N, Z, P} for the input **θ**. The output of the fuzzy controller u has three fuzzy sets: {N, Z, P}. These fuzzy sets are shown in the following figures.

(N = "Negative" , Z = "Zero" , P = "Positive")

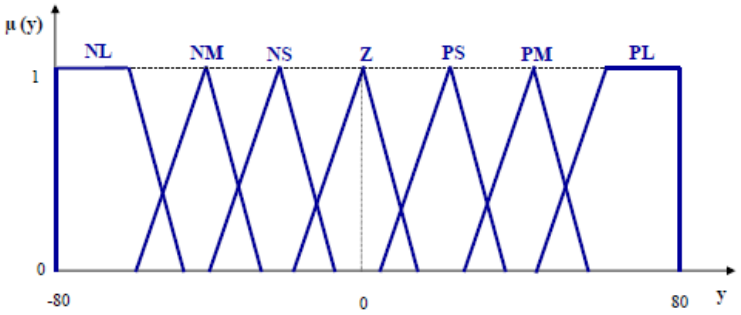


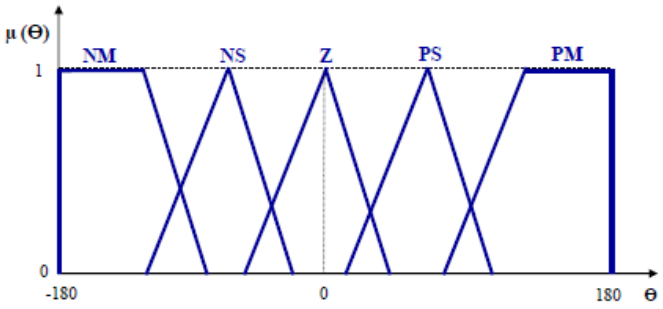
The table of rules

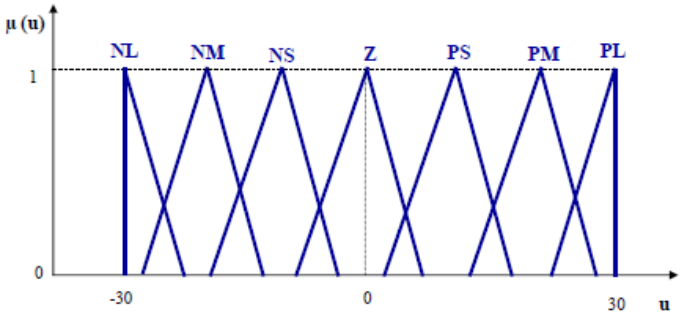
Y\ɵ	N	Z	P
N	P	P	P
Z	P	Z	N
P	N	N	N

7- Repeat Q (6) if we change the fuzzy sets of the inputs to be: {NL, NM, NS, Z, PS, PM, PL} for the input **y** and {NM, NS, Z, PS, PM} for the input **θ**. The output of the fuzzy controller u has seven fuzzy sets: {NL, NM, NS, Z, PS, PM, PL}. These fuzzy sets are shown in the following figures.

(NL = "Negative_large", NM = "Negative_medium", NS = "Negative_small" , Z = "Zero", PS= "Positive_small", PM = " Positive_medium", PL = "Positive_large")







The table of rules

Y\θ	NM	NS	Z	PS	PM
NL	PL	PL	PM	PM	PS
NM	PL	PL	PM	PS	NS
NS	PL	PM	PS	NS	NM
Z	PM	PM	Z	NM	NM
PS	PM	PS	NS	NM	NL
PM	PS	NS	NM	NL	NL
PL	NS	NM	NM	NL	NL